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SOHO ULTRAVIOLET CORONAGRAPH SPECTROMETER (UVCS)

MISSION OPERATIONS AND DATA ANALYSIS

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1.0 Introduction

The scientific goal of UVCS is to obtain detailed empirical descriptions of the extended solar corona as it evolves through the solar activity cycle and to use those descriptions to identify and understand the physical processes responsible for coronal heating, solar wind acceleration, coronal mass ejections (CMEs), and the phenomena that establish the plasma properties of the solar wind as measured by "in situ" solar wind instruments.

The Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory (SOHO) has made major advances in identifying the physical processes responsible for solar wind acceleration, and it has made the first high resolution ultraviolet spectroscopic measurements of CMEs. The UVCS has resulted in over 220 scientific publications.

2.0 UVCS Research Highlights

Highlights: Coronal Holes and Fast Solar Wind

The fast, low-density component of the solar wind flows steadily at about 600--800 km s^{-1} in interplanetary space. This high-speed flow emerges primarily from open magnetic structures known as coronal holes, and often expands to fill most of the heliosphere. Variations in the fast solar wind have been shown to have an impact on the Earth's global climate as well as a direct connection to activity in the Earth's Van Allen radiation belts, sometimes leading to electrical disruptions in satellites. UVCS has made significant progress toward identifying the physical processes that heat the extended corona and accelerate the solar wind by measuring densities, outflow speeds, anisotropic temperatures, and abundances in the acceleration region of the wind. Recent UVCS results concerning coronal holes include the following:

Plasma Properties of Equatorial Coronal Holes: UVCS observations allow the extended heating and acceleration rates to be parameterized as a function of coronal hole geometry, density, and latitude. This information can be used to gain further insight into identifying the processes that generate the high-speed wind. At solar maximum, coronal holes of varying size and shape appear at all latitudes and last for several solar rotations. UVCS has measured the properties of several equatorial coronal holes from 1998 to 2001. Miralles et al. (2001a) found that outflow speeds and perpendicular most-probable speeds of O^{5+} in an equatorial hole were approximately 3 times *lower*, at similar heights, than in the large polar coronal holes from solar minimum (1996--1997). *ACE* found that the wind speed at 1 AU associated with the equatorial hole was 600--700 km s^{-1}, implying that the bulk of the wind acceleration had to occur above 3 $R_{\odot}$. This stands in start contrast to the solar-minimum polar holes, which undergo most of their O^{5+} acceleration below this height (e.g., Kohl et al. 1998).

Ion Cyclotron Wave Dissipation Theory: The surprisingly extreme plasma conditions observed by UVCS at solar minimum have given rise to new theoretical studies of cyclotron resonance as an ion heating and acceleration mechanism (McKenzie et al. 1997; Tu and Marsch 1997; Hollweg 1999; Cranmer et al. 1999). Evidence is mounting that the required high-frequency (10--10,000 Hz) waves are produced high in the corona, probably via MHD turbulence or plasma

instabilities, and are not generated at the solar surface (e.g., Cranmer 2000).
Polar Plumes and Jets: The plasma properties derived from UVCS observations of filamentary inhomogeneities in coronal holes provide quantitative constraints on how much of the solar wind comes from impulsive reconnection events at the base of the corona. UVCS spectroscopy has determined that the most dense concentrations of bright, raylike plumes in polar coronal holes exhibit lower ion kinetic temperatures (Kohl et al. 1997, 1999; Corti et al. 1997) and have lower outflow speeds (e.g., Giordano et al. 2000) than the lowest density---presumably interplume---lines of sight. UVCS has made the first spectroscopic measurements (Dobrzycka et al. 2000) of the polar jets discovered by EIT and LASCO to originate at EUV bright points and extend into the high-speed solar wind.

Recent CME Highlights

Observations of coronal mass ejections (CMEs) demonstrate *SOHO's* unique capability to combine high resolution imaging with sensitive spectral measurements to obtain the morphology, evolution, and plasma parameters of the ejected gas. Specifically, EIT and SUMER observations contain information about the initiation; LASCO contributes the morphology and expansion speed; and UVCS provides the plasma density, temperature, ionization state, and Doppler shift velocity of CMEs at heights of 1.5 to 8 $R_\odot$ (e.g., Ciaravella et al. 1997). The observed plasma motions and Doppler shifts provide information about the sense of twist and magnetic helicity of the erupting flux rope. These quantities provide basic inputs for comparison with magnetospheric measurements by *CLUSTER*, *IMAGE*, and other spacecraft.

Some CME models, though not all, are predicated on a helical magnetic field structure (e.g., Chen 1996; Low 1999). LASCO images show clear indications of helical structure in some events. By adding Doppler shift velocities from UVCS, one can determine whether the structure is twisting (e.g., Chen's model), untwisting (models where the magnetic tether is cut), or simply straightening out (Gibson and Low 1998). Furthermore, by assuming that the untwisting field is anchored in the photosphere, one can determine the sense of magnetic helicity of the erupting flux rope (left- or right-helical).

Measurements of the sense and magnitude of the helicity of CMEs with UVCS are important for space weather predictions because the geo-effectiveness of a CME depends strongly on the north-south component of magnetic field at its leading edge. Flux ropes with southward directed fields at the leading edge reconnect more strongly with the Earth's magnetic field and therefore produce more intense geomagnetic storms.

Recent highlights concerning CMEs include the following:

CME Statistics: As the sunspot cycle rose toward solar maximum, the solar magnetic field evolved from a simple axisymmetric structure at minimum to a contorted structure at maximum, and *SOHO* observed the CME rate increase from 0.3 to 3.5 events per day. At solar minimum, the CMEs are mostly confined to low latitudes, while at solar maximum the latitude distribution widens but still has a smaller hump near the equator. The speed distribution of CMEs develops a high speed tail (St. Cyr et al. 1999). We do not know what to expect as the field simplifies back toward its solar minimum configuration, except that **the most powerful flares and largest geomagnetic storms occur after solar maximum**, so we expect the most powerful CMEs as well.

Helical Motions: UVCS and LASCO observed helical motions within CMEs. For example, in the event of December 12, 1997, several strands of cool CME gas were observed to rotate around one another (Ciaravella et al. 2000). The observed Doppler shifts indicate a left-handed helix untwisting at a rate of about 10^{-3} radians/s. The sense of magnetic helicity is as expected for a northern hemisphere event.

Post-CME Reconnection: Magnetic reconnection is believed to play a crucial role in the initiation of CMEs, and in the reconfiguration of coronal fields after a CME event (often seen as a two-ribbon flare). Some CME models predict a current sheet that stretches from the top of the post-CME arcade to the bottom of the rising magnetic flux rope (e.g., Mikic and Linker 1994; Lin and Forbes 2000). On March 23, 1998, LASCO observed an unusually slow CME while a beautiful arcade brightened in EIT images in Si XI, Fe XV and Fe XII. UVCS observed a narrow bright feature where the UVCS slit intercepted the line between the arcade and the CME. **This feature, visible only in the highest temperature lines of [Fe XVIII], Ne IX, and Ca XV, indicated temperatures around 6 x 10^6 K at the expected location of the predicted current sheet.** Existing theoretical models of reconnection are ambiguous on the partition of energy among heat, kinetic energy and nonthermal particles, but the observations are broadly consistent with their expected energy budget (Ciaravella et al. 2001b).

Extended CME Heating: The thermal evolution of CME plasmas after ejection from the Sun is rather poorly understood. Some models suggest that conservation of magnetic helicity implies comparable power going into kinetic energy and heat (Kumar and Rust 1996). **We now have the first observations of C III, O V, and O VI lines at 3.5 $R_\odot$ which show that heat input comparable to the CME's total kinetic energy was required in one event (Akmal et al. 2001), and similar, though less tightly constrained results were found for another event (Ciaravella et al. 2001a).** These measurements are based on CME onset conditions from EIT, electron column densities from LASCO, and local electron density, temperature and ionization state measurements from UVCS.

3.0 UVCS Instrument Status

UVCS is expected to continue performing at full scientific capability for many more years. Star observations and coordinated observations with *Spartan 201* have shown the UVCS radiometric calibration to be stable within < 10 % for the entire mission. The absolute radiometric calibration in the primary wavelength ranges is believed to be known to within ±20%, which is sufficient for all proposed observations. No flight software changes have been needed. All mechanisms are performing nominally except the Lyα channel grating drive which continues to degrade; use is restricted, but scientific function is redundantly provided by the O VI channel grating drive and a redundant optical path that is used to observe wavelengths near H I Lyα. That path is also used to observe spectral lines in second order such as Mg X, Si XII, and several others. The second order calibration is known to about ±50%. The calibration of the UVCS White Light Channel is not in agreement by about a factor of two with other instruments. A coordinated effort to resolve this discrepancy is in progress. Spectral and spatial resolutions, the wavelength scale, flat field variations, the pointing and absolute spatial scale, and stray light levels are stable and well characterized. The number of operations for all mechanisms is within design limits. Instrument operational temperatures are expected to remain within acceptable ranges.

The UVCS XDL detector for the O VI channel is performing well. There is no significant degradation to the efficiency except on about 20% of the photosensitive area which is used to detect Lyα. Incremental increases in high voltage are used to maintain the efficiency for the Lyα portion to within 5% loss. A voltage increase from the original 200 engineering units (EU) to 205 EU in January 2000 restored full efficiency. Nine additional increases of 5 EU are possible without exceeding the maximum allowable value of 250 EU. Voltage increases of 5 EU every 1.2 years is expected to keep efficiency loss at < 5%. The high voltage for the Lyα channel XDL detector has been turned off since November 1998 because it draws about 50 % of the maximum tested high voltage current and because it has regions of elevated background up to ×5. This detector is still operational and is treated as a back-up detector for Lyα observations.

4.0 UVCS Calibration and Characterization

The UVCS Calibration Working Group has continued to track the characterization of the instrument and provide calibrations appropriate for each stage of the mission. This information is provided as calibration files which are available though the SOHO archive or from SAO. During the past year, an improved set of calibration files were released that addressed various characteristics of the instrument such as the variations in sensitivity across the instrument aperture and the differences between the Lyα Channel and OVI Channel calibrations.

5.0 Data Access

UVCS level 1 data (including all synoptic observations, all CME Watch observations, data from special observations more than one year old, and data analysis software and calibration files) have been made available from the *SOHO* Archive and from SAO. There have been over 48,000 science FITS files (data volume of 3.9 GB) requested and obtained via the *SOHO* Archive. UVCS Mission Logs and a tutorial for new users that includes a corona model code have been updated and made available from SAO via the UVCS web site. All requests for observations from outside sources have been granted.

6.0 Support for Guest Investigators and Other Scientists Not Directly Associated With UVCS

There are 48 UVCS publications by investigators outside of the UVCS team. These projects which depend on support by the UVCS team are another indication of the breadth and impact of the UVCS results within the solar community.

SAO continues to update the UVCS Tutorial which is aimed at familiarizing new users with UVCS data products, data reduction software and data analysis methods including a coronal model code useful for analyzing UVCS observations. SAO continues to support the scientific work of new researchers and the solar community through the distribution of data products, collaborative scientific programs, and participation in SOHO campaigns from the SOHO/EOF and MEDOC.

7.0 Education and Public Outreach

Recent EPO Highlights

UVCS scientists are involved in numerous EPO activities involving K-12 students and teachers; undergraduates from small colleges and Historically Black Colleges and Universities (HBCUs); and the general public. Activities from the past year include: 1) making science presentations to elementary and high school students, 2) serving as research advisors to students from small colleges and HBCUs, 3) being interviewed for local TV, and 4) answering science questions from students via the Internet. Brief highlights of major UVCS EPO activities are describe below:

SOHO 5th Year Anniversary and Sun-Earth Days 2001. Ten UVCS scientists made presentations associated with SOHO's fifth anniversary. The talks were located at nine venues including SAO, the Museum of Science (Boston), the Christa McAuliffe Planetarium (Concord, NH), and the Macmillan Space Center (Vancouver, BC). About ten thousand people attended these events and many times more heard radio interviews or saw TV coverage.

SOHO Education Portfolio. Miralles, et al. created a new lithograph with text for the widely used SOHO Education Portfolio. The lithograph demonstrates how the UV corona varies with time over the solar cycle.

Southern University Partnership. Strachan, et al. are involved in a new initiative to increase the number of minority students and institutions competing for NASA research programs. SAO has partnered with Southern University at Baton Rouge (SUBR) to provide visiting lectures, Web-based tutorials, summer research projects, and mentoring to students.